A Close-Up Look at Power Supplies

A power supply doesn't really supply power—your electric company does that. What a power supply supplies is the correct type and level of power you need to operate a particular piece of equipment. This month, Dave shows us...how it works.

Are you ready for more theory 'n practice views and discussions of amateur radio gear and accessories, friends? Well, we're tuned right to your wavelength and another popular subject is lined up for discussion both this time and next month: power supplies. We'll begin with "How It Works" descriptions of main components in a power supply, trace current flow to visualize how everything works in tandem, then check out some commercially available power supplies. The overall study promises to be quite interesting (given half a chance, power supplies can be quite exciting items—especially homebrewed ones. Really!). We have plenty of ground to cover, so let's get rolling!

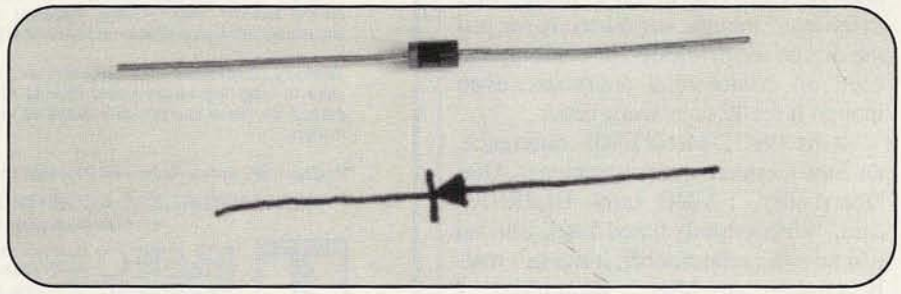

Photo A. A modern silicon diode like that used in a power supply (top) is quite small, but very effective in changing AC to pulsating DC. Below the diode is its pen-drawn schematic symbol. Note that the band on the diode's left side corresponds to the symbol's cathode (or "base") on the left side of the drawing. Current flows through the diode from left (cathode) to right (anode).

Transforming Energy to Our Needs

Changing household-type 120-volt alternating current (AC) to 12 or 13 volts direct current (DC) for powering amateur gear involves three basic steps: *transforming* or "stepping down" the AC voltage, *rectifying* it to make pulsating DC, then *filtering* out the AC ripple. Although possibly not a "basic" step, a means of *regulating* the output voltage so that its light or no-load and full-load values stay within tolerable limits is also included in most modern power supplies. Let's begin with an overview of how transformers work.

As Don Stoner discussed in one of his late 1997 "In Theory" columns, applying DC to a coil wound on a nail or iron core will produce an electromagnetic field capable of attracting small metal particles. What do you suppose would happen if AC were applied to such a coil (*just imagine; don't try it—dinking with household 120-VAC power is dangerous*). An electromagnetic field would start to build or expand, but, before reaching a "fixed maximum level," the applied AC would change its positive and negative polarities. The field would then collapse and another field would begin building or expanding in the opposite direction. Assuming the frequency of applied AC was 60 Hertz (Hz), the field would literally vibrate in place as it changed direction 60 times per second. Now suppose we place an insulated second coil near (or wind it on top of) the first, or primary, coil. The continuously expanding and collapsing lines of (electromagnetic) force will *induce* voltage applied to the primary winding *into* the secondary winding: this is *transformer action.* Note there is no electrical connection between the windings; an electromagnetic field is their only link. Interesting, eh?

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The amount of voltage induced into one coil (secondary) by the other coil (primary) is determined by the turns ratio between the two coils. If both primary and secondary have 100 turns (a 1:1 ratio) and 120 VAC is applied to the primary, the secondary's output will be 120 VAC (assuming negligible losses). But if the primary is 100 turns and the secondary is 10 turns (a 10:1 ratio), the output will be 12 VAC. Get the idea?

Transformers in power supplies operate at a very low frequency (60 Hz), thus an iron core is used to assist primary-to-

By Dave Ingram, K4TWJ

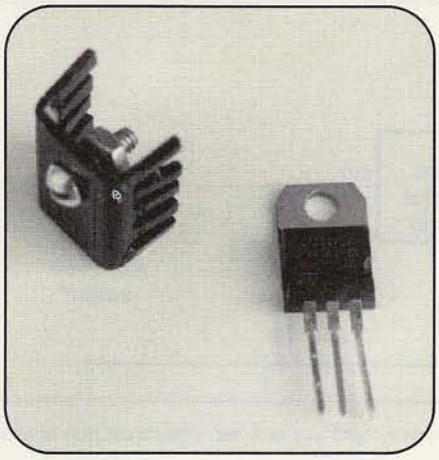

Photo B. A 7812 three-pin regulator capable of handling 12 volts at up to 2 amps and a small bolt-on heat sink for cooling is often used in small power supplies. Sometimes, the regulator is bolted to the power supply's metal case (with special washers for insulation) for even more effective cooling.

secondary coupling. Since that core must respond to rapid changes in magnetic flux, it's made of numerous laminated sections stacked on each other like a deck of playing cards (this helps reduce losses within the transformer core). Developing new core designs and materials, incidentally, is a big-time pursuit among transformer manufacturers.

Diodes and Regulators: Super Semis!

One of the special rewards in writing this monthly *CQ VHF* column is occasionally relating true tales from amateur radio's magnificent past to a new generation of amateurs. Hopefully, some of our younger readers will remember these tales, pass them along to another generation of amateurs, and continue the legacy. Bear with me while I introduce diodes and semi-conductors with one such tale.

Few people may realize it, but crude forms of solid-state diodes have actually been with us since the early days of spark gap transmitters and crystal set receivers (1910s and 1920s), and well before the era of vacuum tubes. Indeed, articles in the *Pacific Radio News* magazine (see "*Pacific Radio News:* the *CQ* Connection") described the fine art of "galena hunting" to wireless operators of yesteryear.

Following those tips, ship radio ops on shore leave searched the countryside for special galena rocks (which looked similar to fool's gold). Back aboard ship, each rock was mounted in a metal holder and a fine wire called a "*catwhisker*" was moved over its surface to locate spots exhibiting the best "*detector action*" (highest front-to-back ratio). A handful of galena rocks was vital to radio operators, as signals from a super-strong transmitter aboard a ship passing by while leaving port easily burned out prime detector points. A really good operator could quickly change galenas while receiving a message without missing a full word of copy. Ah, those golden days of the past truly proved "the operator rather than the rig made the difference!" Galenas faded into the woodwork during the era of vacuum tubes, then re-emerged a few decades later in highly refined form. These "chunk" components inspired the development of transistors and kicked off today's era of solid-state electronics.

Today's Diodes

Two types of diodes are popular today: the sensitive germanium type used in detectors and switching sections of transceivers, and the more hearty silicon type used as rectifiers in power supplies. Look closely at a clear glass detector diode like a 1N34 and you can see a tiny replica of an old-time detector (complete with galena chip and catwhisker) in its casing.

Silicon diodes have the unique ability to pass current in only one direction. In other words, they're a one-way valve for electrons. A diode can thus change AC (like that from a transformer's secondary winding) to pulsating DC. Modern silicon diodes are enclosed in a solid plastic case with wires extending from each end, as shown in Photo A. The *cathode*, or negative end, is marked with a solid band and the *anode*, or positive end, is unmarked. Looking at a diode's schematic symbol (also in Photo A), current passes "against the arrow" or from negative to positive.

During production, silicon diodes can be *doped* with special additives to establish their voltage and current ratings. These are usually specified as *Peak Inverse Voltage* or PIV (maximum voltage before breakdown) and *average current* (safe mA or ampere handling ability). Rather than being labeled accordingly, diodes are marked with a "1N—" number that can be referenced on manufacturers' data sheets.

A good rule of thumb when using diodes in power supplies is selecting

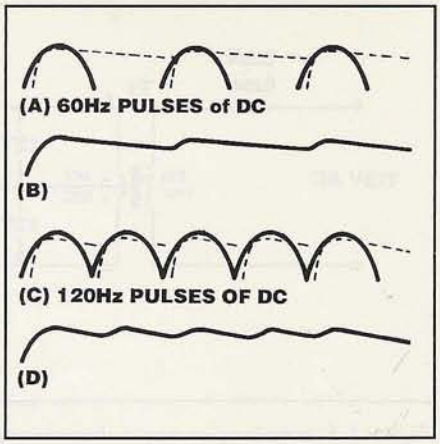

Figure 1. Graphic study of filter capacitors smoothing pulsating DC from the output of a rectifier into "closer to pure DC." (A) and (B) show the output of a half-wave rectifier, while (C) and (D) show the output of a full-wave rectifier. See discussion in text.

types with PIV ratings two to three times larger than the supply's output voltage, and two or three times greater than the supply's maximum output current.

Three-terminal regulators are a shining example of how far technology has advanced during recent times. These little wonders contain a sensing and voltage referencing section, an error amplifier, a small "pass transistor" element, and can be visualized as a miniature power IC. Regulators packaged in TO-220 cases look like power transistors and handle up to 2.5 amps. They are usually marked with "78——" numbers (like 7806/6 volt, 7812/12 volt, etc.), and one is

Pacific Radio News: The CQ Connection

In our brief look back at the history of semiconductors, I mentioned a magazine called *Pacific Radio News*. This magazine also warrants recognition of its own. It started in California during the teens, its name was changed to *Radio News* during the 1920s, and then shortened to *Radio* in 1929. In the 1940s, *Radio* moved east and split into two magazines: one which would become today's *Audio* magazine, and another devoted to ham radio, titled *CQ—The Radio Amateur's Journal*. That's right, *CQ* and its new sister publication, *CQ VHF*, along with their predecessors, have been keeping amateurs informed and enthused ever since the days of spark! Long live *CQ*!

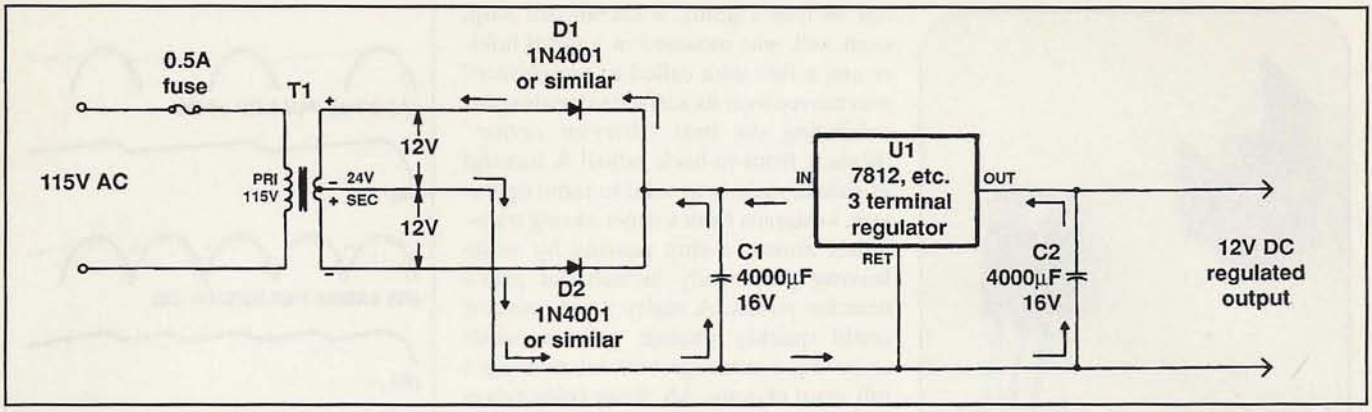

Figure 2. Schematic of an easy-to-homebrew power supply for operating a 5-watt FM talkie or 6-meter QRP rig at home. See discussion in text.

shown, along with its bolt-on heatsink for cooling, in Photo B. Integrating a regulator in a power supply is simple: unregulated voltage is applied to its input pin, its control pin is grounded for referencing, and regulated voltage is taken from its output pin.

Filtering Out the Hum

After being stepped up or down in level by a transformer and rectified by one or more diodes, a power supply's voltage is a series of single polarity pulses called *pulsating DC*. Large-value filter capacitors like those shown in Photo C are then used to "filter out AC ripple" (which you would hear as hum in a rig), or to smooth the pulses into almost pure DC. This action is accomplished as follows.

First, rectified pulses charge up the filter capacitors. Then, in between pulses, the filters attempt to discharge through the load. Assuming that the filters are large enough in capacitance (microfarads, or µf) and the DC pulses are close together, the output voltage will be almost hum-free. Figure 1(A) gives us a closer look at this filtering process. A solid line indicates pulsating DC from the rectifier, and a dotted line shows how capacitors "fill in the blanks" between pulses.

Notice that the resultant output/waveform in Figure 1(B) still contains "waviness," or a significant amount of AC ripple/hum. Assuming we could add an extra set of DC pulses in the blanks being filled by the filters and increase the capacitors' values (in other words, change from a half-wave to a full-wave rectifier arrangement and use beefy filter caps), the output would be almost pure and hum-free DC. This arrangement is shown in Figure 1(C) and (D).

Technically orientated readers may now be visualizing yet another way filters remove AC hum—by shunting or bypassing it to ground or around the load. Yes, and that viewpoint also illustrates how larger value filters are more effective than smaller filters. How so? Using the formula **Xc = 1/F(Hz) x C (farads)**, we find that a 100-µf capacitor's reactance (Xc) at 60 Hz is 166 ohms and a 4000-µf capacitor's reactance is only 4.16 ohms. Only a small amount of AC ripple will be shunted to ground by 166 ohms, but most of that ripple will pass through 4.16 ohms without opposition.

Confusing? I will simplify it: just use 100-µf (or larger) capacitors in power supplies for vacuum tube gear and 4000-µf (or larger) capacitors for solid-state gear (overkills are rare and never hurt), and enjoy hum-free DC!

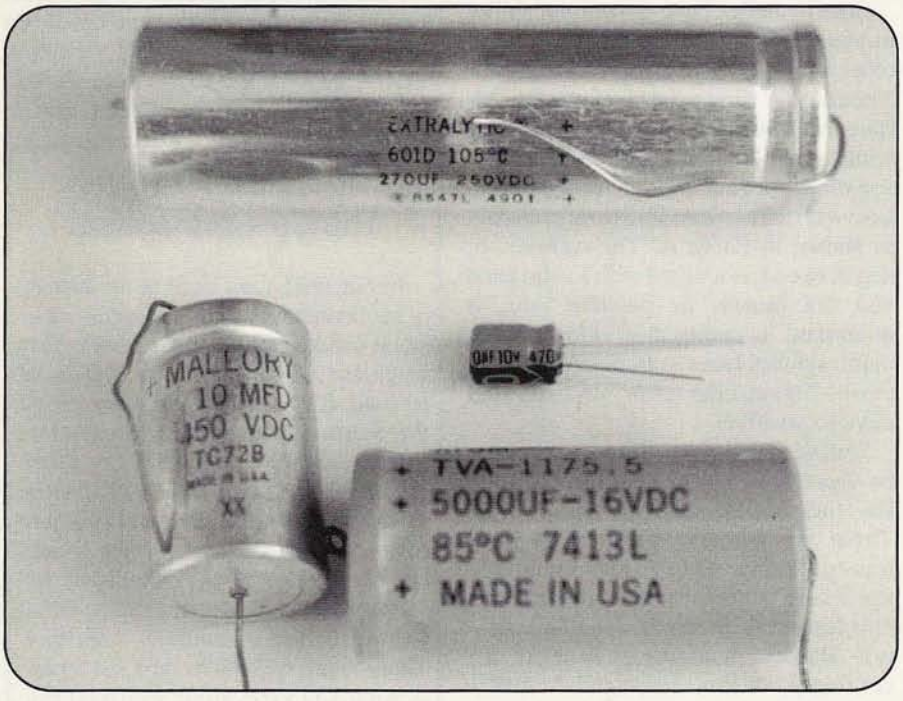

Photo C. Filter capacitors are made in a variety of shapes and sizes according to the value (in microfarads, or µf) and working voltage. The upper capacitor is 270 µf at 250 volts, for example, while the small middle capacitor is 470 µf at 10 volts and the lower capacitor is 5000 µf at 16 volts. Finally, the one on the left is 10 µf at 150 volts.

Homebrew a Power Supply? Sure!

Now let's bring everything together in a complete power supply that you can quickly assemble and trace both DC and AC current paths to visualize how various components work in tandem. Since half-

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wave rectifiers are prone to AC hum and bridge rectifiers will be discussed in next month's column, let's look at a full-wave design you can use with readily available 24-volt center-tapped transformers. Folks seem to overlook or shy away from 24-volt transformers, so they're often available at bargain prices in hamfest fleamarkets. Rectified "full wave" rather than "bridge style," they form the heart of a neat 12-volt DC supply.

The circuit of our bare bones power supply is shown in Figure 2, and its theory of operation follows. Let's begin by freezing an instant in time when the top of T1's secondary is positive with respect to the center tap, and the bottom is negative with respect to the center tap. At this instant, current flows from the center tap, up through C1 and C2 (visualize U1 as a low value resistor; I will explain it later), through D1, and back to the secondary's top wire. Current did not flow through D2 because it was reverse-biased and because the secondary's bottom wire was negative rather than positive.

During the next instant in time, polarities on secondary wires toggle (the top becomes negative and the bottom becomes positive). Current then flows from the center tap, through C1 and C2, through D2 and back to the secondary's bottom wire (which is positive). Current did not flow through D1 during this time because it was reverse-biased by a negative polarity on the secondary's top wire.

In between pulses, C2 attempts to discharge through the load/rig, thus removing AC ripple/hum from the DC output voltage. Simultaneously, sensing circuitry in U1 increases and decreases the resistance of its "pass circuitry" to oppose minute fluctuations in voltage at its input. These fluctuations result from AC "riding on DC" that was not completely filtered out by C1. In other words, C1, U1, and C2 work together to produce pure DC output. Savvy?

Incidentally, if you wish to build a small power supply like the example in Figure 2 for your FM talkie or 6-meter QRP rig, here are some notes to help you along the way: T1's secondary should have three wires, one of which is the center tap. Using your ohmmeter, you should measure/read 24 volts between "end wires" and/or 12 volts (AC) between the center tap and either end wire. The transformer should be rated at 2 to 4 amps, which usually equates to an overall size of 3 to 4 inches square. **CAUTION: Never touch primary, secondary or AC power cord wires when "plugged in": the resulting tooth-rattling shock can be hazardous to your body!**

Silicon diodes rated at 50 volts and 4 to 6 amps (or greater) are good choices for D1 and D2. I like IN4001s, as they are rated at 50 volts and 15 amps and cost less than 20 cents each. Two 4000 µf 16-volt capacitors should be fine for C1 and C2, but there's nothing wrong with overkill—especially if local amateurs like to critique each others' signals. I found a pair of 20,000 µf/16 volt capacitors at a hamfest fleamarket for one dollar each. Now that's a deal no one could pass up!

The three terminal regulator is a 12-volt/2-amp, TO-220-cased item I purchased for less than $2 (Mouser 511-L7812CV). If you have a new style talkie that runs on 6 volts, substitute a 6-volt/2-amp regulator (Mouser 511-L7806CP) and a 12-volt center tapped transformer. Remember to heat-sink the regulator, include a .5-amp fuse in the transformer's primary line, and enjoy using your home-brewed power supply!

Technically Speaking

Transformers accurately illustrate a basic law of physics which states that energy cannot be created or destroyed, but only changed in form. They also show us how everything in electronics equates, or "balances even," so to speak. Consider, for example, the transformer depicted in Figure 3. Its primary winding is 100 turns and its secondary is 10 turns: a 10-to-1 ratio. With 120 VAC at .1 amp applied to the primary, voltage on the secondary will be 12 volts at 1.0 amp. Multiplying 120 volts times .1 amp equals 12 watts. Multiplying 12 volts times 1.0 amp also equals 12 watts. In practice, actual secondary current will be around .95 amps, or 11.5 watts. The difference (.5 watts) is dissipated in heat loss, which consists of *hysteresis losses* (losses due to resistance to rapid changes in the transformer core), *Eddy currents* (induced currents that flow in circles), and *copper losses* (resistance in coils).

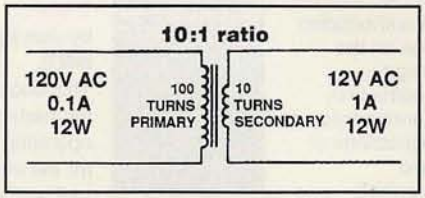

Figure 3. The total energy on the secondary coil of a transformer is always equal to the energy on the primary coil (ignoring minor heat losses), illustrating the basic law of physics that energy can neither be created nor destroyed, only changed.

After a couple of hours of operation, you can feel the heat loss with your hand (the transformer will be slightly warm). Manufacturers are continually improving transformer designs. One familiar example is the new Hypersil core for maximizing efficiency. This is a fascinating area of study, and we have only skimmed its surface!

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Looking Ahead

Next month, we'll continue with some interesting "How It Works" views of bridge rectifiers and commercially made power supplies for both low and high power rigs. Stay tuned! Meanwhile, drop us a note on special topics/subjects you would like to see featured here in "How It Works."

Hot note: Watch for a hands-on story of communicating via AO-27 "QRP Style"—coming soon in this column. It's a blast! 73, Dave, K4TWJ